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ABSTRACT

Programed mastery learning materials on matrix algebra were studied by 59 eighth-grade boys. Both experimental and control groups were divided into high- and low-ability groups. The experimental group reviewed all three instructional units until students achieved mastery, but the control group reviewed only Unit 3. Test scores of the treatment group increased over the sequence, especially between Units 1 and 2 and Units 1 and 3. Scores of the control group decreased. High-ability students scored higher in both groups, but the difference between the three units was not influenced by ability or by a combination of treatment and ability; the treatment was equally effective for both levels of ability. There was no difference in time spent learning Unit 1 by treatment vs. control groups. The treatment group spent significantly longer learning Units 2 and 3, but review time decreased from Unit 2 to Unit 3. The control group required more time to learn Unit 3 to mastery than the treatment group. Treatment aided the learning efficiency of the low-ability students, as well as retention of the materials ten days later. (GDC)

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Learning Time and Teaching for Mastery

Graham Ward

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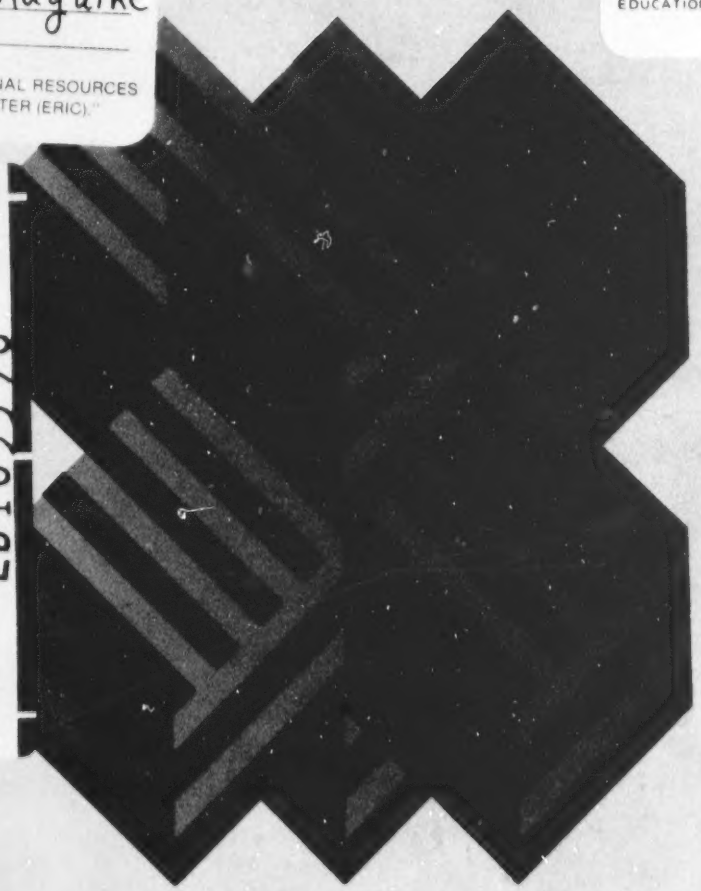

LEARNING TIME AND TEACHING FOR MASTERY

by

Graham Ward

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CHAPTER 1

MASTERY LEARNING AND TIME: STUDY OBJECTIVES

The basic idea of mastery learning or teaching for mastery is that, given appropriate instructional conditions, 'most students can learn what the schools have to teach' (Bloom, 1974 a: 53). Although there are considerable differences in the rates at which students learn, it is argued that if the conditions are made appropriate for learning and that if students are willing to work at the learning task, almost all will reach the criterion of satisfactory understanding and proficiency if they are given enough time (see Carroll, 1970).

Brief History of Mastery Learning

The history of modern mastery learning ideas has been traced in a number of reviews (Bloom, 1968, 1974; Block, 1971; Jones, 1974; Contreras, 1975; Srivastava, 1976; Torshen, 1977) from the pioneering individualized instructional plans of Burk, Washburne and Morrison in the early part of this century to Bloom's work in the 1970's.

Burk's instructional plan involved the identification of the minimum level of performance required for mastery, the need to master a unit before advancement to the next unit and the provision of the extra time necessary for the mastering of unlearned material. Washburne reported that:

> schools that have tried Burk's plan ... have found that it worked, that it saved time (and) that it made school life ... more efficient for teachers and pupils (Washburne, 1940:251).

Washburne's own Winnetka Plan was developed from Burk's ideas. This strategy was an individualised learning system which attempted to cater for individual differences in learning rate by permitting each student to proceed essentially at his own pace. This involved

> allowing every child to master each unit of his work before he goes on to the next unit, without being held back by slower children or forced forward by faster ones too rapidly for mastery (Washburne, 1932:2).

At the University of Chicago Laboratory School Morrison used frequent diagnostic tests to determine whether each student needed additional time and help in a teaching plan which involved pretesting, teaching, testing the result, adapting the procedure, teaching and testing again until learning was achieved. By providing the time and help required, student achievement

was increased and the total amount of time spent in new learning was ultimately reduced (Morrison, 1926).

It has been pointed out that although these early plans attracted considerable interest they were not widely adopted. It would seem that this was due largely to the 'lack of the technology required to sustain a successful strategy' (Flock, 1971:4).

The development of programmed instruction, which represented the application of Skinner's reinforcement theory of learning to instruction, introduced such a technology (Skinner, 1954, 1968) and the work of Gagné further developed understanding of the learning process and of the conditions necessary for adequate learning (Gagne, 1965).

Carroll (1963), using the principles of modern learning theory, published a seminal paper entitled A Model of School Learning which identified the major factors influencing students' success in school learning and showed how the factors were interrelated. Carroll began with the amount of time that a student needs to learn a given task to a predetermined satisfactory level of understanding. He termed this level the mastery criterion level. If the student does not spend sufficient time to learn the given task, then the degree of his learning will fall short of the mastery criterion level.

The time actually spent in learning was seen to be controlled by two factors: the time allowed to learn the given task and the student's willingness to use the time made available for learning. The degree of learning achieved by the student was seen by Carroll to be determined by the interaction of five factors. Three of these factors were internal to the student: aptitude, perseverance and ability to understand and profit from instruction; two of the factors were external to the student: the quality of instruction provided and the time allowed.

Bloom in a paper Learning for Mastery took Carroll's idea a stage further.

> If the students are normally distributed with respect to aptitude for some subject and all students are given exactly the same instruction (in terms of amount and quality of instruction and learning time allowed) then achievement measured at the subject's completion will be normally distributed. ..If ... the kind and quality of instruction and learning time allowed are made appropriate to the characteristics and need of each learner, the majority of students will achieve subject mastery (Bloom, 1968:3).

In addition, Bloom put forward the view

> :hat 95 per cent of ... students ... can learn a subject to a high level of mastery ... if given sufficient learning time and appropriate types of help (although it was accepted that) some students will require more effort, time and help ... to achieve this level (Bloom, 1968:4).

Characteristics of Mastery Learning Strategies

In an unpublished review Srivastava (1976) discussed three major contemporary mastery learning approaches and identified six characteristics common to them. He considered Bloom's Learning for Mastery approach, Keller's Personalized Systems of Instruction approach and the Audio-Tutorial Mastery Learning approach.

Srivastava suggested that these mastery learning approaches all:

a assume that almost all students are capable of achieving the objectives of the course and that all students are willing to make an attempt to achieve these objectives;

b require the objectives of the course to be stated in behavioural terms;

c require the entire course of instruction to be organized into small learning units, each unit corresponding to 1-2 weeks of instructional time;

d prescribe a level of performance usually termed "mastery criterion" which a student must attain before he is allowed to proceed to the subsequent units of instruction;

e employ criterion referenced measurements, that is, they test whether the student has or has not achieved mastery rather than grade him in relation to the performance of his peers;

f employ feedback corrective procedures to assist students to attain mastery of the prescribed objectives.

(Srivastava, 1976:16).

It is the last characteristic which is perhaps the most distinctive feature of these learning approaches. The original instruction might be group based and paced by the teacher, or it might be individualized and self-paced by the student, but formative testing is always used after the initial instruction to identify areas of difficulty and to provide feedback information to pupils and teachers so that remediation measures may be employed to facilitate learning.

Gronlund ('974) discussed a number of other approaches, including IPI (Individually Prescribed Instruction) and PLAN (Program for Learning in Accordance with Needs) which also used diagnosis and review procedures.

As Bloom pointed out:

> The key to the success of mastery learning strategies largely lies in the extent to which students can be motivated and helped to correct their learning difficulties at the appropriate points in the learning process (Bloom, 1974a: 5).

The correction is accomplished through diagnosis and review. The use of these procedures involves those students who initially fail to reach the mastery criterion level spending additional time so that they can overcome the specific difficulties which have been identified.

Mastery Learning and Time

Since the publication of the papers by Carroll (1963) and Bloom (1968) a number of mastery learning strategies have been developed (see Gronlund, 1974, Srivastava, 1976 and Torshen, 1977). Some of these strategies are self-paced and others are group-paced, but all set fixed achievement criteria and provide students with varying amounts of time and help to permit virtually all students to attain the mastery criterion level. This is in contrast to the traditional pattern of teaching where a fixed amount of time is set for the learning tasks and where achievement is allowed to vary.

> In setting time as the central variable in school learning, Carroll produced a major shift in our thinking about education.... If teachers and curriculum makers can define an appropriate criterion of achievement, then it becomes the responsibility of the teachers and the schools to provide the time necessary for the students to attain the criterion. If time is the central variable and the necessary time is provided, then the attainment of the criterion is possible for all students who can be motivated to use the time they need (Bloom, 1974b: 683).

The present study was concerned with investigating some of the relationships between a mastery learning strategy involving the use of a diagnostic review procedure in a self-paced learning program and the time taken in learning.

The total time taken in studying a unit of work using a diagnostic and review procedure is made up of the time spent in the original learning of the material plus the time spent in the review learning. Review or

re-learning necessarily involves the expenditure of additional time to provide correction, allowing the learning of unlearned material or enabling the relearning of misunderstood material.

The additional learning accomplished by the review procedure may so increase the effectiveness of learning in the next unit in the sequence, that it reduces the time taken in such learning. Additional time spent in re-learning the earlier units in a series thus may be traded for smaller amounts of time spent on the original learning of later units. On the other hand, the review procedure may result in more time being taken on the original learning of later units in the series, in an effort by the students to increase the probability of avoiding the need for review. In this case, the increased time spent on the original learning of the unit is exchanged for reduced review time on the same unit. Both effects may be present together and the net result will depend on which effect is the greater.

If the achievement score on the formative test associated with a unit is increased, either because of improved entry behaviours brought to the study of the unit, or because of more careful study patterns engendered by the requirement to review, then such improved achievement will be gained at the cost of the additional time spent in reviewing the previous unit or in the original learning of the unit. However, in learning a unit, an increase in achievement on a test means that there will be less additional material to review in order to reach the criterion level on that unit, and this will reduce the review time required.

The effectiveness of the original learning of units in a sequence may be measured by calculating the percentage mark on the first formative test per minute of time spent on the original learning of the unit. Review time is also involved, so that the measurement of the effectiveness of the total learning of each unit would need to take into account the time spent on the review of the previous unit. An appropriate measure to use would be the percentage mark on the first formative test per minute of the total time spent in learning since taking the first formative test on the previous unit. Both of these measures of learning effectiveness could be used to measure the extent to which increased time is exchanged for improved achievement.

Objectives of this Study

It was the purpose of this study to examine the effects of a diagnostic and review procedure on achievement, on the time taken, and on the efficiency of learning over a sequence of three units in a self-paced learning program, and to investigate the effect of mathematical ability on these variables.

CHAPTER 2

A REVIEW OF RESEARCH ON MASTERY LEARNING

This review examines studies concerned with the effects of instructional strategies involving diagnosis and review on achievement and retention. In addition the review considers investigations concerned with time taken in learning a unit or a series of units.

Mastery Learning Strategies and Cognitive Outcomes

There is a considerable body of experimental evidence bearing on the effectiveness of mastery learning strategies compared with conventional non-mastery instructional procedures.

Mastery Learning and Achievement

Srivastava (1976) in a comprehensive review of research on the effects of mastery learning on achievement divided the studies he considered into four categories based on the research design characteristics used.

There were three studies lacking a control group. These gave the impression that the mastery learning strategies used (all of which had a diagnostic and review component) led to greater student achievement. The difficulties of interpretation of these studies, which reported only the proportion of students receiving A and B grades, included variations in the mastery levels accepted by the various studies, the lack of comparisons with control groups, the effects of withdrawals from courses on the reported final grade percentages, the nature of the tests used to measure student achievement, and the variations and changes in grading policy, in grading criteria, and in expectations of student performance.

Five studies attempted comparisons with control groups which had been selected from previous semesters or preceding years. It was suggested that these too showed that achievement was increased. The assumptions in these studies of similarity and comparability of the samples, variations in the standard of performance accepted as indicating mastery and the effects of withdrawals from courses all provide problems in the interpretation of the reported results.

Five studies employed control groups selected from student populations of the same semester or the same year as the experimental groups, but had

not compared achievement of the groups using statistical tests. Again these studies supported the view that learning to criterion levels before progressing to later stages in a course improved student achievement. However, the uncertainty of comparability between the experimental and the control groups was cited as a major difficulty in generalising the results.

Twenty-nine studies used statistical tests of significance to compare the achievement scores of the experimental and control groups. Not all of the experimental and control groups were randomly selected from the same or even from similar student populations so that there were design features in many studies which contributed to uncertainty in the interpretation of the findings. Many of the studies reported were at the college level and compared review and relearning procedures with conventional lecture methods in a variety of study fields. Four of these college level studies reported that the performance of the experimental groups was not significantly different from that of the control groups but nineteen investigations reported significantly higher mean scores in the experimental groups. There were six reports of studies which had been conducted at the school level. Three studies in the fields of Mathematics or Statistics showed significant differences in favour of mastery learning; three in the field of Geography did not.

Three studies not examined by Srivastava gave similar results in that the finding was positive in the case of the study in the field of Mathematics, but negative in the two cases involving the Social Sciences. Contreras (1975) reported details of a study by Gaines which involved twenty-eight classes in fifth to eighth grade Anthropology and which found no significant difference between mastery and non-mastery treatments on a post-test. A study by Jones (1974) showed that only the middle aptitude group of mastery treatment classes in seventh grade Geography achieved significantly higher mean scores than the control classes. In addition, Burrows and Okey (1975) reported significantly higher achievement and retention in a treatment which provided review prescriptions, compared with three other treatments which did not involve review, when eighty-four fourth and fifth grade students were taught Geometry.

Hall (1977) concluded after examining twenty reports published between 1974 and 1976, involving twenty-five studies in all (eleven of which were at the school level, eight at college level and six at university level), that:

> at no level do the reported results give unequivocal support to the claims made... that (mastery learning)... leads to significantly higher achievement (Hall, 1977:45).

At the school level six of the studies reported higher achievement, but five did not. At the college level four studies showed superior achievement, but four produced no significant difference. At the university level three studies indicated higher performance but three studies did not.

The studies which reported significantly higher achievement in the experimental groups at the school level included the subject fields of Mathematics (3), Reading, Language, Arts, Physics and Geography (in the middle aptitude group only). Subject fields which reported no significantly higher achievement included Mathematics, Geography (2) (for low and high aptitude students only), Language (for intern teachers only) and Art (for intern teachers only). There were considerable differences in the nature of these studies in terms of the experimental treatments and the control treatments. In some of these studies mastery at the appropriate level was not a prerequisite for advancement.

Nevertheless, Block and Burns in a review of selected research studies of teaching procedures using diagnosis and remediation at both the school and college levels were more positive:

> The findings of... mastery learning research suggest mastery approaches to instruction do work.... In quantitative terms mastery approaches have usually produced greater student learning than non-mastery approaches (Block and Burns, 1977:25).

Only one known study (Hall, 1977) of mastery learning has been undertaken in Australia. This research involved two investigations. The pilot study showed a very highly significant positive effect on achievement in Computer Studies, while in the main study, concerned with Directed Numbers, positive effects on achievement were found in three out of four schools and on retention in one school out of four schools.

The evidence in favour of strategies involving diagnosis and review is thus inconclusive. Srivastava's comments are significant.

> While there are a large number of studies whose results cannot be generalized due to the.., methodological problems involved... there are a number of methodologically and analytically sound studies which indicate that mastery learning strategies lead to improvement in student achievement particularly in subject areas where learning is hierarchical (Srivastava, 1976:41).

Contreras had earlier reached a similar conclusion. She felt that it was difficult to draw firm conclusions but said that

> except for mastery studies in social sciences, reports of findings seem to indicate that mastery procedures facilitated achievement in comparison with control or non-mastery procedures.... It might be inferred that hierarchically sequenced subjects ... lend themselves more readily to mastery procedures than do social science subjects in which the sequencing of materials may be logical but not necessarily hierarchical (Contreras, 1975:41).

There were considerable differences between the experimental treatments in the studies reviewed and the results were far from conclusive. Nevertheless, there is evidence that achievement is facilitated by instructional strategies which involve diagnostic and review procedures, especially where the learning is hierarchical in organisation.

Mastery Learning and Retention

Only a few studies have been located which have examined the question as to whether mastery-learning type approaches involving diagnosis and review yield greater retention than do non-mastery approaches.

In all of these studies retention was measured by a delayed post-test administered after a period had elapsed following the learning sequence. The length of delay between the summative test of the course and the retention test varied considerably from study to study. The studies also shared considerable variation in the nature of the experimental and control treatments involved.

Block (1970) found that there was a linear relationship between the percentage of material mastered and student retention as measured by a post-test administered two weeks after the close of the instruction. The higher the level to which each unit had been originally mastered the greater the retention, but only the 85 per cent and 95 per cent mastery treatment groups retained to a significantly greater extent than the non-mastery treatment group. The groups for which the mastery criterion levels were 65 per cent and 75 per cent did not show significantly greater retention than the non-mastery group.

Contreras (1975) used a similar design to study the effects of learning to 70, 80 and 90 per cent criterion levels compared with a control group for which there was no specified mastery level. The delayed post-test used to measure retention was administered three weeks after the

instruction had ended. The subject material was concerned with population geography and the results were negative indicating that higher criterion levels did not facilitate retention any more than lower criterion levels.

A four week course on Functions of Cities was taught to twenty classes at the seventh grade level in a study by Jones (1974). The final test of the course was re-administered 17 days later to test retention. The mastery treatment facilitated greater retention for high and middle aptitude students but not for low aptitude students. There was some reason to believe that the difference in the results for the aptitude levels might have been the result of significant reading difficulties in the low aptitude group providing problems in both the original and the review learning.

Fagan (1975) taught four hundred and seventy students at Grade 7 a unit on Transportation Geography and no significant difference was found between the retention scores of the experimental and control groups after a period of three weeks.

Romberg, Shepler and King (1970) in an earlier study showed that mastery learning students retained material learned at nearly the same high level they had reached on the final tests. Shepler had taught a unit on Statistics to twenty-five sixth grade students and King had taught the same group another unit on Mathematical Proof. The teaching strategy involved diagnosis and review learning. The students were retested for retention twenty-eight days after the unit on Statistics and fourteen days after the unit on Proof. The retention ratio was 0.95 on the average for both units, and the correlation between achievement (immediate post-test) and retention (delayed post-test) was +0.78 and +0.75 for the two units respectively. The study design did not compare the learning with that of a control group, so that the results could not be interpreted as indicating that the mastery learning approach facilitated greater retention than a non-mastery approach.

In a study by Burrows and Okey (1975), in which eighty-four fourth and fifth grade students were taught a unit on geometry over a period of fourteen days, significantly higher scores were obtained by the group following a diagnostic prescriptive process on both an immediate post-test and one conducted fourteen days later.

The Australian study by Hall (1977) showed a positive effect on retention in one school out of the four schools concerned in an investigation which involved teaching a unit on Directed Numbers.

There is thus some evidence to suggest that a diagnostic and review procedure facilitates retention in subject areas where learning is hierarchical but that it is much less successful in improving short term retention in other subject fields where learning is not hierarchically arranged but is composed largely of factual material.

Mastery Learning Strategies and Time Taken

Only a small number of studies have been located which have examined the incremental or decremental effects on time taken on learning of mastery learning strategies involving correctional feedback or diagnostic and review procedures (Merrill, 1965; Merrill and Stolurow, 1966; Merrill, Barton and Wood, 1970; Block, 1970; Arlin, 1973; Anderson, 1973; Jones, 1974; Contreras, 1975).

All but one of the studies examined showed that diagnostic and review procedures involved more time being spent in the complete learning of a unit or series of units than was spent by a control group not using a correction procedure. Merrill, Barton and Wood (1970) reported that the review group took less time than the non-review group to complete the set of units, but that the difference failed to reach statistical significance.

Few of the studies reported the original learning time and the review time separately. Both Merrill (1965) and Block (1970) showed that more time was spent on the original learning by the experimental groups. Only the studies by Merrill and Associates examined the changes in original learning time over the series of units. It would seem that the subject's perception of the correction and review process was a key factor in influencing the time taken on the original learning. Merrill (1965) suggested that when review is perceived negatively subjects are encouraged to spend more time on the original learning in an effort to avoid the review material. Merrill, Barton and Wood (1970) suggested that if subjects knew that they would receive a step-by-step explanation they would spend less time working out an answer. The three Merrill studies all involved programmed learning with a teaching machine presentation. The presentation frames were immediately followed by the problem frames and the correction and review procedure immediately followed feedback from the problem frames. The results may well be specific to this form of teaching.

Block (1970) showed that the mean amount of time spent in review was related to the criterion level of performance required of the group.

The higher the criterion level required the more the time that was spent in review. Review time, of course, was additional to the original learning time. Changes in review time over a series of units were examined by Arlin (1973) who found that review time did not significantly decline over the sequence but Anderson (1973) reported that not as much time was required for help in later units.

If the time spent on learning is related to achievement a measure of learning efficiency is obtained. Block (1970) showed that the 95 per cent criterion group learned the third unit in a three unit sequence more efficiently in terms of the mark scored per minute of original learning time than did the control group, but the results for the other criterion groups learning to different levels of mastery did not all support this finding. Arlin (1973) used a measure which involved the time spent in minutes in each unit divided by the number of frames answered correctly, and showed that the rate (i.e. learning efficiency) of original learning increased across the units.

Conclusion

Arising from this review, it seemed important to undertake a study which would re-examine effects of maintaining an 85 per cent criterion level on the original learning time, on the review time and on the total elapsed time spent in learning. In addition it was considered essential to examine the efficiency of learning, as measured by the marks scored in the formative test per minute of time spent on the original learning of each unit of the sequence, and as measured by the marks scored in the formative test of each unit per minute of time spent on the original learning of each unit plus the review time spent in relearning the previous unit to criterion level. Trends in all these variables over the three unit sequence would be of considerable interest, and the scores obtained in the summative and retention tests divided by the total elapsed time over the sequence should be compared. It would also be useful if the effects of mathematical ability on the results obtained were investigated.

CHAPTER 3

THE DESIGN AND CONDUCT OF THE STUDY

The objectives of the study were to examine in a self-paced, individualized, three-unit, hierarchical learning sequence the effects of diagnostic and review procedures, mathematical ability and the interaction between these two variables on:

1. the scores obtained in the formative tests on each unit,
2. the time taken in the original learning of each unit, the review learning of each unit and in the complete learning to criterion standard of each unit,
3. the percentage scores obtained on the formative test on each unit per minute of time spent on the original learning of each unit and on the original learning of each unit plus the time spent on the review of the previous unit, in each case adjusted for the length of the unit,
4. the scores obtained in the summative and retention tests of the course,
5. the percentage scores obtained in the summative and retention tests per minute of time spent on the original learning plus the time spent on the reviews of all units in the sequence, and
6. to examine changes in the scores obtained in the formative tests, the time taken and the percentage scores per minute of time spent from unit to unit over the three unit sequence.

The Sample

The sample group used in the study comprised students from two eighth grade mathematics classes at a boys' independent school located in an outer Melbourne suburb. The two classes, one of thirty students and the other of twenty-nine students, were taught by different regular class teachers. They were parallel classes on the school time-table.

The school has a comprehensive entry and the two classes were unstreamed. The boys in the school at this level had been allocated to forms on the basis of the results obtained in the previous year and an attempt had been made to ensure an even distribution of pupils scoring at all levels in the basic subjects in each of the forms.

There were four forms at this level in the school and the two class groups used in the experiment were selected because the teachers concerned were prepared to become involved in the experiment.

The school serves a middle and upper-middle class socio-economic group. There was a considerable variation in academic ability within the eighth year level and within the two classes. No claim can be made that the experimental population is representative of a wider population.

Assignment of Sample

The subjects from the two forms involved in the experiment were pooled and were randomly assigned to two new classes, one of thirty students and the other of twenty-nine students. One of those classes was then randomly assigned as the experimental group and the other class became the control group. There were thirty students in the experimental or treatment group and twenty-nine students in the control group.

The treatment group was then randomly assigned to one teacher and the control group to the other. This latter procedure was adopted in order to make the supervision and the classroom organisation less onerous for the teachers and to allow clear distinctions in treatment to be maintained between the two groups.

Mathematical Ability Sub-groups

Both groups had previously been tested using the Morton Mathematics Test (Elkins, Andrews and Cockrane, nd). The experimental and the control groups were each divided into two sub-groups on the basis of the test results. Those students scoring above the median in each group formed the high mathematical ability sub-groups and those scoring below the median formed the low mathematical ability sub-groups. There were fifteen subjects in the treatment high ability group, fifteen in the treatment low ability group, fifteen in the control high ability group, and fourteen subjects in the control low ability group. There were no significant differences between the mean scores of the treatment and control groups as a whole, between the two high ability sub-groups or between the two low ability sub-groups.

Treatment Variable

There were three differences in treatment between the experimental and the control groups.

The experimental group was given the opportunity to review and relearn unmastered material and was required to reach the mastery criterion level

before proceeding to the next unit in the sequence. In addition, each student in the treatment group was given enough time to study so that he reached the mastery criterion level.

These three variables were absent in the control group. Students proceeded directly to the next unit whatever their score on the formative tests in the first two units, that is, they were not given the opportunity to review and relearn, were not required to reach mastery criterion level before proceeding to the next unit in the sequence and were not given time to study to reach the mastery criterion level. However, they were required to learn the material of Unit 3 to mastery criterion level.

Definition and Measurement of Variables

The dependent variables were defined and measured as follows:

1 Original achievement was measured by the percentage score obtained in the 20 item formative test administered at the completion of the first learning of each unit. This test was teacher corrected and scored.

2 Original learning time was measured by the elapsed time in minutes spent in the original learning of each unit prior to the formative test. Such learning time was self-paced by the learner. Each student was required to record the time he commenced and the time he completed his study.

3 Total original learning time was measured by the sum of the original learning times of each unit in the sequence.

4 Review learning time was measured by the elapsed time in minutes spent in the relearning of each unit to mastery criterion level, such time included time spent on any tutoring involved. The mastery criterion level was set at 85 per cent of the items correct on the twenty item formative test for each unit, or the score on the first review test plus as many items on subsequent review tests as were necessary to bring the total number of items correct up to seventeen (i.e. a total of 85 per cent original items completed correctly). The starting and finishing time of all review sessions, including tutoring, was recorded by the students and these times were spot-checked by the teachers.

5 Total review learning time was measured by the sum of the review learning times of each unit in the sequence.

6 Unit learning time was measured by the sum of the original learning time and the review learning time of each unit. This variable measured the total elapsed time spent in studying the material of each unit.

7 Total learning time was measured by the sum of the unit learning times of each unit. This variable measured the total elapsed time spent in studying the material of the entire sequence of units.

8 Original learning rate was measured by the original learning time for each unit divided by the total number of frames in the unit. It was recognised that the frames varied considerably in length and in difficulty, but it was considered that an average measure would indicate differences in the rate of original learning and would give a satisfactory measure of differences between the units in the mean time spent per frame. Unit 1 consisted of fifteen frames, Unit 2 had twenty-three frames and Unit 3 had thirty-two frames.

9 Original learning efficiency was measured by the original achievement divided by the original learning time adjusted for the length of each unit. The units varied in length. The percentage scores on the Unit 1 formative test were divided by the number of minutes spent on the original learning on that Unit. The Unit 2 formative test scores were divided by 0.65 (i.e. 15/23) of the number of minutes spent on the original learning of that Unit; the Unit 3 scores were divided by 0.47 (i.e. 15/32) of the number of minutes spent on the original learning of that Unit. This procedure adjusted the variable so that it was the percentage score per minute of elapsed time spent in the original learning of each unit adjusted for the length of the unit.

10 Unit learning efficiency was measured by the original achievement divided by the sum of the original learning time, adjusted for the length of the unit, plus the review learning time of the previous unit. The Unit 1 score was the unit formative test score divided by the number of minutes spent on the original learning; the Unit 2 score was the unit formative test score divided by the sum of 0.65 of the number of minutes spent on the original learning of the unit and the number of minutes spent in review on Unit 1; the Unit 3 score was the unit formative test divided by the sum of 0.47 of the number of minutes spent on the original learning and the number of minutes spent in review on Unit 2. This variable was the percentage score per minute of elapsed time spent on learning since the formative test on the previous unit adjusted for the length of the unit.

11 Achievement was measured by the percentage score on the 20 item summative test administered at the end of the sequence of units with no opportunity for revision. This test was teacher corrected and scored.

12 Retention was measured by the percentage score on the 20 item retention test administered ten days after the summative test with no opportunity for revision. This test was teacher corrected and scored.

13 Achievement learning efficiency was measured by dividing the percentage score on the summative test by the total elapsed time spent on learning the three units.

14 Retention learning efficiency was measured by dividing the percentage score on the retention test by the total elapsed time spent on the learning of the three units.

The independent variable was defined and measured as follows:

15 Mathematical ability was measured by the raw score on the Morton Mathematics Test. This test was designed to test numeracy or computational skills. It was considered that the results of this test adequately reflected variations in mathematical ability.

Controlled Variables

The classroom conditions in which the learning took place, and the teachers' roles were kept as similar as possible in the two class groups involved in the experiment in order to control variables other than the treatment.

The classroom conditions in both classes were similar with students sitting individually in rows. The teachers were asked to ensure a minimum of conversation and pupil interaction so that the initial learning would proceed through the use of the original instructional material provided. This was the same for both classes. All initial learning was based on this material and all responses were written on the materials provided.

The teachers' instructional activities were restricted. The teachers were asked to act as supervisors and administrators, except in the latter stages of remediation when tutoring was to be provided for those students who had failed to reach mastery criterion level using the written materials provided. These procedures were adopted to provide control for the effect of pupils on each other's learning and for the effect of teachers on the students' learning.

Orientation of Teachers

The teachers taking part in the study were provided with an instruction sheet which outlined the designed differences between the experimental group and the control group, and which detailed the procedures to be followed.

Discussions were held between the teachers prior to the commencement of the experiment and during its course. Data were collected regularly and opportunity was taken to discuss the procedures being used.

There was no evidence of deviations from the prescribed procedures.

Learning Materials

The subject matter selected for the experiment was the material produced by Block for his 1970 study.[1]

The development of the material is described in detail by Block (1970). The final form consisted of three programmed textbooks on Matrix Arithmetic. The first unit had fifteen frames dealing with Definition and Types of Matrices, the second unit had twenty-three frames covering Zero, Transpose and Identity Matrices and the Equality of Matrices and the third had thirty-two frames explaining Addition and Subtraction of Matrices.

These units were based on the programmed textbook Introduction to Matrix Algebra by Vidya Bhushan of the Education and Development Center, University of Hawaii. This textbook had been revised to form a one hundred and five frame program divided into the three units described above. It was then abridged by removing some thirty-five repetition and practice frames to produce the three booklets used in the initial instruction.

Achievement Tests

Three formative tests were provided for each of the three units in the course. These were a twenty item formative test and two parallel review tests. The tests were criterion-referenced and were based upon a task analysis of the content of each unit. A summative test of twenty items covering all the subject matter of Units 1, 2 and 3 was used as an

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[1] The experimenter's thanks are expressed to Professor J.H. Block for his kind permission to use the material in this study.

immediate post test and a parallel form of this test provided a retention test which was used ten days after the sequence had been completed.

Review Material

The review material was the unabridged, longer, one hundred and five frame programmed textbook. A sheet was provided for each unit which listed references to groups of frames in the review program appropriate to each problem on the formative or the review tests. The frames to be so reviewed were arranged in a hierarchical sequence for each question, so that the earlier or prerequisite learnings required in each sequence were studied first.

Procedures

Initially both the treatment and the control groups were provided with copies of the programmed textbook, Matrix Arithmetic, Unit 1. Students were required to read the instructions, to note the time when they began to work and then were asked to study the material at their own pace. The students' responses to the questions in the texts were written directly into the books supplied. As students finished the unit they noted the time on the program, and they obtained a copy of the formative test from the class teacher. When the test was completed it was handed to the teacher for marking. Activities such as private study or reading, unconnected with the subject matter of the experiment, were provided for students who had completed the test.

At this point the treatment of the two groups varied. The control group proceeded directly to Unit 2 and was given no opportunity to relearn or revise the material. They were not given their tests. The treatment group, on the other hand, were required to restudy the material if they had not reached the mastery criterion level at the first attempt at the formative test.

The mastery criterion level was set at seventeen out of twenty items correct. This mastery level corresponded to the 85 per cent level suggested as optimum for cognitive and affective outcomes by Block (1970). Each student in the experimental group who required review was given a copy of the extended three part programmed textbook and a mastery sheet. The mastery sheet indicated a set of frames appropriate for relearning each missed item on the formative test. If the student scored at less than mastery criterion level (i.e. less than seventeen items correct) the sets of frames to be studied from the review program were shown on the mastery sheet.

The difference between the student's score and eighteen determined the number of such sets to be learned, and the allocation of the precise sets to be learned was made in a random order from tables used by Block (1970). The time the review learning began and finished was noted by the student. Each student relearning was supplied with his formative test, the mastery sheet indicating the sets of frames to be reviewed and the review program.

On the completion of the relearning the student obtained a copy of the review test. The questions corresponding to the sets of frames reviewed were circled on the test paper by the teacher and only those questions were attempted. When the review test was completed it was handed to the teacher for marking. The mastery criterion level on this test was set at one less than the number of questions attempted so that the mastery criterion level on the unit remained at 85 per cent correct. This procedure was intended to reduce the possibility of additional review sessions being required.

If mastery level was reached at this point the student began work on Unit 2. If mastery was still not reached the review sets not mastered were reviewed again using the same materials and a second review test was then attempted. If further study was required at this point, tutoring was provided either by the teacher or by students who had already achieved mastery. The first review test was used again, if necessary.

A note was made on the program or the mastery sheet of the starting and the finishing times at each stage of the procedures, so that original learning time (defined as the elapsed time from commencement of learning to the formative test) and review time (defined as the elapsed time spent in all review and tutoring to mastery) could be calculated, and the total elapsed time to mastery criterion level obtained.

The same process was used in Unit 2, with progression to Unit 3 in the experimental group contingent on obtaining either a minimum of 85 per cent correct on the formative test, or such number of questions on the subsequent review test or tests as would bring the score up to that level. In the control group there was automatic progression to Unit 3.

In Unit 3 both the treatment and the control groups were required to reach mastery criterion level. Review frames were prescribed for all students failing to reach the mastery criterion level of 85 per cent correct on the formative test. The review tests were used in sequence to

test the review or relearning. A record was kept of all elapsed time spent on the original learning and on review learning.

The class time in the control group was organised so that all students began Unit 1 together and sat for the formative test independently when they had finished their study. When the test had been completed it was handed to the teacher for marking, and the students were permitted to read or to undertake other school work until the end of the class session. They all began the study of Unit 2 at the start of the next class period and followed this learning with the appropriate formative test as they finished. The same procedure was followed with Unit 3, but students who required review as a result of their scores on the formative test in Unit 3 began relearning at the beginning of the next class period, and continued this review in a self-paced fashion until the required mastery level was reached. Alternative school work was provided for those students who finished the sequence before other students.

All students in the treatment group began their study together and sat the formative test as they finished their original study. They were permitted to read or to do other school work until the end of the class session. The formative test papers were marked by the teacher. At the beginning of the next class period, students from the treatment group either began the next unit if they had reached mastery criterion level, or began the review learning having been provided with the necessary materials. As the relearning was completed students took the review test. An attempt was made to correct the tests during the class period if sufficient time remained for productive study. If this was not possible, correction was done by the teacher after the class session. Students were allowed to read or to do other schoolwork while they waited. The review learning or original learning, as the case might have been, was started at the beginning of the following class period. Learning was self-paced throughout.

When all subjects had completed the learning or review of Unit 3 to mastery criterion level a twenty item summative test was administered. This test was taken on a Monday by all but four students in the treatment group and two students in the control group. Four students (two in the treatment group and two in the control group) were absent from school on the day the test was given. These students sat for the summative test at the first opportunity after they had returned to school. Two other

students had not completed the learning of Unit 3 to mastery criterion level due to earlier absences in the case of one, and to extremely slow progress in the case of the other. Both of these subjects were given sufficient extra time to complete their study of Unit 3 and attempted the summative test two days after so doing.

A retention test was administered ten days after the original test without the opportunity for revision. The retention test was given to each of the six students who sat for the summative test later than the other students, at an interval of ten days after they completed the summative test. There was thus no difference in time between the summative and retention tests for these six subjects and the other subjects in the experiment.

Collection of Data

The formative, review, summative and retention tests were teacher marked. The learning times during original learning and during review learning were calculated from the times of starting and times of finishing noted by the students on the original programmed learning materials or on the review sheets.

Statistical Tests

The significance of differences between the means of groups was examined by t-tests and the significance of trends in the means from unit to unit was tested by analyses of variance. The analyses of variance were also used to investigate the effects of mathematical ability.

Tables reporting summaries of the data and the results of these tests are grouped in the Appendix.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter is divided into three sections. Findings concerned with achievement are examined first. The second part of the chapter examines findings concerned with time and the third section is concerned with findings which attempt to relate scores and time.

The group which used a diagnostic and review procedure and which was required to reach the mastery criterion level before proceeding to the next unit, with the necessary time being provided for such mastery, will be referred to as the treatment group. The group which did not use a diagnostic and review procedure and which proceeded directly to the next unit upon completion of the earlier units will be referred to as the control group.

Findings Concerned with Mean Scores on Tests

> Proposition 1. There is no difference between the mean scores of the treatment and control groups on the first formative test in Unit 1, but the treatment group gains higher mean scores on the first formative tests in Units 2 and 3.

The proposition of no difference in the mean scores on the first formative test was examined in order to ensure that any differences found in later comparisons of scores on the formative, summative or retention tests were not the result of an initial difference between the two groups involved in the experiment. The subjects had been randomly assigned to the groups and the treatments of the groups had been the same. For these reasons it was expected that no significant difference would be found. The results reported in Table 1 confirmed that there was no significant difference in the means of the scores on the first formative test for Unit 1.

As a result of the requirement to review and master the material of the preceding unit it was anticipated that treatment group students would possess higher level entry behaviours for a later unit or units, than would the control group students. Such entry behaviours would lead to better comprehension during the later study and this would lead to higher scores in the later units. Moreover, it was expected that the review requirement would encourage students to study the later units with greater initial care and attention in order to reduce the probability of being required to

engage in relearning. More time would be spent and this would lead to higher scores on the formative tests in the later units.

The control group, on the other hand, was under no such requirement to master successive units. Lower entry level behaviours for later units in the sequence would lessen the effectiveness of the study of these units and the lower motivation and perseverance resulting from the absence of a review requirement could be expected to lead to lower scores on the formative tests.

The results reported in Table 1 show that the treatment group scored significantly higher than the control group in both the Unit 2 and Unit 3 tests.

> Proposition 2. The treatment group shows an increase in the mean scores on the first formative tests over the sequence of Units 1, 2 and 3 whereas the control group shows a decline.

The treatment group was required to review material following the completion of the Unit 1 formative test and was required to relearn the material of that unit in order to reach the mastery criterion level before proceeding to the next unit. As a result of this review procedure higher cognitive entry behaviour skills would be available and these together with higher perseverance and motivation and a longer study time would lead to higher formative test scores on Unit 2 than on Unit 1. A similar pattern could be expected between Unit 2 and Unit 3. Progressive improvement toward an upper limit of mastery standard could be anticipated over a series of such units. It was argued that these factors would not be operating in the control group. Thus it was predicted that the scores would decline from unit to unit as cognitive entry behaviour levels became progressively lower and less sufficient for the more advanced material of later units and as perseverance fell due to the lack of the requirement to master.

The analysis of variance reported in Table 2 showed that the two groups differed significantly in the rate of change between the units. The differences between the groups became progressively greater and are reported in Table 3. The treatment group showed an improvement in mean test scores across the three units. The difference between Unit 1 and Unit 2 and between Unit 1 and Unit 3 were both significant. However, there was no significant difference between Unit 2 and Unit 3. In addition, the control group showed a decline in scores across the units. There were significant

differences between Unit 1 and Unit 3 and between Unit 2 and Unit 3 but there was no significant difference between Unit 1 and Unit 2.

Thus the significant difference between the groups across the three units resulted from an increase in the mean scores in the treatment group and a decline in the mean scores in the control group. The increase occurred early in the sequence in the treatment group, whereas the decline in the control group scores occurred later.

> Proposition 3. The treatment group has higher mean scores on the summative and retention tests than the control group.

The higher levels of initial learning on Unit 2 and Unit 3 resulting, presumably, partly from higher entry level behaviours and partly from greater motivation and perseverance in learning, together with the more complete learning of Units 1 and 2, could be expected to produce higher scores on both the summative and retention tests, despite the requirement that both groups should reach mastery criterion level on the Unit 3 formative tests.

Both tests included items drawn from the content of all three units but the tests were independent and were not of comparable difficulty so that no significance can be attributed to differences in scores between them, in each of the groups.

The data reported in Table 1 show that the treatment group scored significantly higher in both tests. The higher scores were achieved at the cost of additional time spent in original learning and in review learning during the sequence.

> Proposition 4. In the treatment group the mean scores on the first formative test of those required to review increases from Unit 1 to Unit 2 and from Unit 2 to Unit 3.

Table 4 shows that the number of students required to review fell from unit to unit. The mean formative test scores for each unit and for the subsequent unit are reported. Sixteen students were still required to review Unit 3. The mean scores of those students for each unit are shown in Table 4.

The t-Tests (correlated, one-tailed) reported in Table 5 showed that there was a significant difference between the scores on Unit 1 and Unit 2 of those reviewing Unit 1 but that there was no significant difference between the scores on Unit 2 and Unit 3 of those students reviewing Unit 2. In the group required to review Unit 3, there was a significant difference

in scores between Unit 1 and Unit 2 and between Unit 1 and Unit 3, but there was no significant difference between Unit 2 and Unit 3.

Thus the increase in scores which has been attributed to the review procedure was significant between Unit 1 and 2. However, there were no significant improvements in performance between Unit 2 and Unit 3, among those students required to review.

The initial improvement did not continue and just over half of the students were still required to review Unit 3.

One possible explanation for this finding is that there was a significant difference in the difficulty of the material covered in Unit 3, or in the Unit 3 formative test. If this were so, it would explain the lack of significant improvement by those required to review.

Another possibility is that there were some students who found it difficult to maintain improvement even with the aid of the review procedure. Whether such students would show improvement in later units with longer exposure to the review procedures is a question which would require more research using longer learning sequences.

> Proposition 5. The difference in mean scores between the treatment and the control groups is not affected by ability, and the difference in mean scores between the units is not affected by ability or by a combination of treatment and ability.

The extent to which the findings reported earlier needed to be modified, when mathematical ability was taken into account, was examined by dividing both the treatment and control groups into two sub-groups on the basis of the Morton Mathematics Test. Those students who scored above the median in each of the treatment and control groups formed the high ability sub-groups, and those who scored below the median formed the low ability sub-groups.

The analysis of variance reported in Table 2 showed that there was a significant difference in the mean scores of the high ability and low ability groups, but that there was no significant interaction between treatment and ability. It can be concluded that the effect of the treatment was not influenced by ability differences.

Similarly the difference between the units was not influenced by ability nor was the difference between the units affected by a combination of treatment and ability.

It may be concluded, that ability differences had no influence on the treatment. The treatment effect was of the same order for both levels of ability.

Findings Concerned with Time

> Proposition 6. There is no difference in the mean original learning times of the treatment and the control groups on Unit 1, but the treatment group takes longer on Units 2 and 3.

The first part of this proposition was examined in order to determine whether any differences which might be found in later comparisons of the time taken in learning were the result of a significant initial difference between the two groups involved in the experiment. The members of the two groups had been randomly assigned and the treatments had been identical up to the first formative test on Unit 1. For these reasons it was expected that no significant difference would be found between the two groups.

The results reported in Table 6 showed that there was no significant difference between the two groups in the mean elapsed time taken to complete the original learning of Unit 1.

It was considered that those students who needed to review material on a previous unit or units and to reach the mastery criterion level on formative tests in each unit would have superior entry behaviours for later units. Consequently, they might be expected to learn subsequent related material more quickly. However, it was also possible that the requirement to review and relearn would act in such a way as to increase the time the treatment group would spend studying the next unit. It was argued that the requirement to review would be perceived negatively and that such review could more likely be avoided by more careful and slower study. The longer and more careful study period might be expected to produce higher formative test scores and therefore a decreased likelihood of review prescription.

The absence of high entry level behaviours in the control group, due to the lack of review of previous units, would make it more difficult for students to complete the unit quickly so that it could be expected that this group would take longer. However, there was no requirement for this group to master the work studied, but merely a demand to complete the unit. Progress might be seen in terms of the completion of the unit rather than in terms of mastery, so that there would be little incentive to spend any more time than was absolutely necessary.

The results reported in Table 6 showed that the treatment group took significantly longer in mean elapsed time on the original learning of both Unit 2 and Unit 3. It followed that the mean total original learning time over the three units was also significantly longer for the treatment group.

> Proposition 7. The treatment group takes less time in review on Unit 3 and less total time than the control group does.

It was argued that, when both treatment and control groups were required to review and to learn to the same mastery criterion level, those students who had mastered the previous two units would require significantly less mean review time on Unit 3 and significantly less mean total elapsed time on Unit 3 than the students who had not been required to master the previous two units.

The treatment group would have possessed superior specific entry behaviours, and would be expected to have studied the unit more carefully and this would have led to formative test scores closer to the mastery criterion level. Students in this group would, therefore, have less material to review and relearn. They would be more accustomed to performing at the high mastery levels required.

On the other hand, it was expected that many students in the group which had not previously been required to perform at the mastery criterion level would find that they lacked the entry level behaviours required for adequate original learning, would have studied the original material in Unit 3 less thoroughly and less carefully, and would, as a result, have scored further from the mastery criterion level in the formative test. These students in the control group would thus have more sets of material to review, would have been less prepared for that review because of their lower entry behaviours, and would have found it difficult to adjust to the new requirements.

The results reported in Table 7 showed that the treatment group took significantly less mean review time and significantly less mean total time on Unit 3 than did the control group. The decline in review time more than compensated for the increased time spent on the original learning. The treatment group in fact required only 60.8 per cent as much time for Unit 3 as the control group.

> Proposition 8. The treatment group spends a longer total time on the review of Units 1, 2 and 3 than the control group on the review of Unit 3.

It was considered that the group using diagnostic and review procedures in Units 1, 2 and 3 would take longer in total review time over the three units than the control group which was required to review only in Unit 3. Material would need to be reviewed and mastered in Units 1 and 2 in addition to that reviewed and mastered in Unit 3. Although higher scores on the formative tests would be expected to result from the review procedures leading to less material being required to be reviewed in later units, more material would be required to be reviewed and mastered over the complete sequence of units.

The results reported in Table 7 showed that there was no significant difference between the groups in the mean total review time spent over the entire sequence despite the difference in the total amount of material to be mastered. The control group spent almost as much time (95.4%) reviewing and relearning Unit 3 material as the treatment group did in reviewing and relearning material on Units 1, 2 and 3.

The quantity of material requiring review in each unit was a function of the extent to which students fell short of mastery levels in the formative tests of each unit. The treatment group, because of higher scores on the formative tests had less material to review in the later units and especially in Unit 3. There was no such requirement for previous mastery in the control group so that the additional time required to review Unit 3 for mastery was almost as much as the treatment group's review times on Units 1 and 2 added together.

> Proposition 9. The treatment group takes longer in mean total learning time on Units 1, 2 and 3 than the control group.

The higher mastery level required throughout the three unit sequence was expected to require and encourage the more careful and complete study of each unit and to lead to more time being spent on original learning. It was expected that the reviews required in Units 1 and 2 by the treatment group additional to that required of both groups in Unit 3 would also take more time.

The results reported in Table 7 showed that there was no significant difference between the groups in total time although the treatment group did in fact take longer (16%). Although the treatment group spent longer in both original learning (26.9%) and in review (4.8%) the total times taken by the two groups were not significantly different.

Proposition 10. The treatment group uses progressively less mean time on review per unit over the sequence of units.

A progressive decline in review time from unit to unit within the treatment group was expected because it was considered that the review procedure would facilitate a more complete mastery of the later units in the sequence. This would be, not only because more careful study was encouraged, but because students would be in possession of higher entry level behaviours for later units. The study of subsequent units would thus be more effective and students would be expected to score closer to the criterion level, or at the criterion level, so that they would have less material to review.

Review time was largely a function of the difference between the score on the formative test and the criterion level. As the total number of sets of frames to be reviewed declined so would the mean review time. The number of students reaching mastery criterion level on the first formative test would be expected to increase from unit to unit and this would further reduce mean review time.

The means of review time for each unit for the treatment group as a whole and for those required to review in Unit 3 together with the corresponding standard deviations are reported in Table 8.

The t-tests (correlated, one-tailed) reported in Table 9 showed that there was a significant difference between the review times of Unit 1 and Unit 2 and between Unit 1 and Unit 3. There was, however, no significant difference between the mean review times of Unit 2 and Unit 3. The decline in review time between Unit 1 and 2 was highly significant, but this decline was not continued between Units 2 and 3. The difference between Unit 1 or Unit 3, however, remained highly significant.

Less time was required in the review in the later two units compared with the first, but the decline was not progressive over the sequence of units.

The review times of students required to review in Unit 3 showed a similar pattern (see Table 9). There were significant differences in the review times taken between Units 1 and 2, and between Units 1 and 3; less review time was used in each case. There was, however, an increase in review time between Unit 2 and Unit 3, although this was not statistically significant. This increase may well have resulted from the greater difficulty of the content of Unit 3.

There would seem to have been a group of students who required continuous review in order to maintain learning at the mastery criterion level. Five students in this group required over thirty minutes review time on the third unit. These five students averaged 52.4 minutes of review time; one student required 100 minutes of review time, although this time almost certainly included some off-task behaviour. The question of whether longer experience with learning at the higher levels would contribute to a lowering of the need for such review requires further investigation.

Table 10 indicates that review time as a percentage of total time declined steadily across the units, and review time as a percentage of original time did likewise. It would appear that as learning became more efficient review became proportionally less important in terms of the time it required. The statistical significance of the reported differences was not assessed.

> Proposition 11. The treatment group uses progressively more original learning time per unit over Units 1, 2 and 3 than the control group. The difference between the treatment and the control groups is not affected by ability and the difference between the units is not affected by ability or by a combination of treatment or ability.

The review procedure in the treatment group was expected to be viewed negatively, and was expected to encourage the maintenance of learning effort in order to increase the probability of mastery on the first formative test. The more careful and complete study thereby encouraged was expected to take longer. In the control group there was no such requirement, so that students could be expected to try to complete the units as quickly as possible.

Table 6 shows that the original learning times increased from unit to unit in both the treatment and control groups. The analysis of variance reported in Table 11 indicated that there was a significant difference between the groups in terms of the mean original times, and that there were significant differences between the units. The treatment group took longer than the control group on the last two units, although both groups did in fact take longer than they did on the earlier unit. The change in original time taken was at different rates for the two treatments. The treatment group used progressively more time per unit than the control group.

Units 1, 2 and 3 cannot be regarded as of equivalent length. Unit 1 had 15 frames, Unit 2 had 23 frames and Unit 3 had 32 frames. The fact

that later units were longer would exaggerate the significance of trend changes in the original time spent in learning.

Accordingly it was decided to compare trends in the original time from Unit 1 to Unit 3 in the two groups by examining changes in the rate of learning each unit. This would largely compensate for the differences in the length of the units. The time taken for each unit was divided by the number of frames in each unit. It was recognized that the frames did vary considerably in length and in difficulty but it was considered that, on the average, this measure would be comparable over complete units.

The original proposition was thus rephrased to read 'The treatment group uses progressively more original learning time per frame over Units 1, 2 and 3.'

It was anticipated that the treatment group would continue to spend progressively more time per frame than the control group. Table 12 reports the mean values of the learning rate in Units 1, 2 and 3 for both groups. The analysis of variance reported in Table 13 showed that, while there was a significant difference between the units, this difference was not dependent on treatment. The rate of change between the units was similar for both groups. The treatment group did in fact spend some 19 per cent of time longer on Unit 3 than Unit 2 but this difference was not statistically significant.

It would seem likely that the unit difference noted was a function of the difficulty of the material. Hierarchical learning sequences frequently become progressively more difficult as more complex and involved material is presented. The increase in difficulty affected the learning times of both groups.

It is possible that the increased entry behaviour of the treatment group enabled the more difficult learning of the later units to be mastered in less time than would otherwise have been the case, although the need to achieve mastery standard would tend to maintain mean per frame work time. The lack of such a mastery requirement in the control group may well have encouraged those students to be concerned merely with completing the units as quickly as possible. The lower entry behaviours of this group would make learning more difficult in later units and thus might be expected to increase learning time. There was no significant difference between the groups in the mean time spent in original learning when this was corrected for the length of the units.

The analysis of variance reported in Table 13 indicates that high ability students spent significantly less time per frame on the initial study and that the effect of the treatment was influenced by the ability of the students. Low ability treatment subjects spent significantly more time per frame. This finding is consistent with the earlier view that perseverance would be increased by the review requirement. The students were apparently encouraged to study the material more carefully. It was concluded that the reported difference between the units was not dependent on ability, nor was the difference a function of a combination of treatment or ability. Low ability students had been encouraged to spend additional time in the original study of the unit, but not at an increasing rate over the sequence of units.

> Proposition 12. The treatment group uses progressively less total learning time per frame over Units 1, 2 and 3. The difference between the units is not affected by ability or by a combination of treatment or ability.

It was argued that the decline in review time per unit would cause a decline in the total time per unit over Units 1, 2 and 3 in the treatment group. The units were not comparable in length so that differences in the original time would have been a reflection of differences in the amount of material to be studied. Moreover, it was likely that there would have been real differences in the difficulty of the material over the three units. The material was hierarchical in arrangement, with more complex and difficult concepts and operations in the later units. This increase in difficulty would be expected to affect the time spent in the original learning. Variations in the length of the units and particularly in the difficulty of the units might be expected to influence review time as well. In order to achieve some comparability between units, the total elapsed time per unit was divided by the number of frames in each unit to provide a measure which took account of differences in the length of each unit. It was considered that such a procedure would provide a satisfactory comparative measure, although it was recognised that the frames varied considerably in length and in difficulty both within the units and between the units.

The results reported in Table 14 and the analysis of variance reported in Table 15 showed that there was a significant difference across the units. Further examination indicated that there was a difference between Unit 1 and Unit 2 and between Unit 1 and Unit 3, but that there was no change

between Unit 2 and 3. Total time per frame declined. Material in the two later units was mastered at a faster rate than in the first unit.

If the earlier contention that Unit 3 contained more difficult material were to be accepted, then the relationship would be even more strongly supported by the data. There was no difference in the total time for mastery per frame between Units 2 and 3. If the material were significantly more difficult, as earlier analyses would appear to indicate, then it would be expected that Unit 3 would take significantly longer than Unit 2. It did not. The more difficult material of Unit 3 would seem to have been mastered at the same rate as the easier material of Unit 2. The more mathematically able students took significantly less time per frame. The rate of change between the units differed significantly between the high and low ability sub-groups.

The improvement in the rate of learning was more marked in the low ability sub-group than it was in the high ability sub-group. The total time taken by the high ability group declined to 56 per cent between Unit 1 and Unit 3, and to 49 per cent in the low ability group. This was an extremely interesting result. Despite the continued dependence of some low ability students on review and relearning procedures, the effect of the treatment was most marked in this group. Learning became relatively more efficient measured in terms of the amount of time spent per frame over the sequence of three units.

Findings Concerned with Scores and Time

> Proposition 13. The treatment group scores more marks per minute of time spent per frame on the original learning of Units 2 and 3 than the control group. The marks per minute of time spent per frame on the original learning of the units increases from unit to unit across the sequence in the treatment group whereas the marks scored per minute of time spent per frame by the control group does not increase from unit to unit. The difference between the treatment and the control groups and the difference between the units is not affected by ability or by a combination of treatment and ability.

Earlier analyses have shown that the review procedure significantly increased scores in the treatment group compared with the control group, and that the review procedure required students to spend more time on the original learning of each unit than the control group. It has also been shown that the scores increased through the sequence of units in the treatment group whereas they declined in the control group. It was expected that

the increase in scores would be greater than the additional time expended on original learning, and that the efficiency of learning as measured in this way would increase across the learning sequence in the treatment group.

Consequently, it was of interest to explore the relationship between the score on the first formative test and the time spent in the original study of each unit. The percentage score on the first formative test was to be divided by the number of minutes spent on the original learning of each unit, but because the units differed in length the time spent was adjusted for the length of the unit measured in frames, so that the percentage mark scored would be proportional to the number of minutes spent per frame. This procedure was adopted so that the percentage mark scored would be related to the rate of original learning per frame in each unit.

The results are reported in Tables 16 and 17. The treatment group scored higher marks per minute of time spent than did the control group. The diagnostic and review procedure facilitated learning in the treatment group and the material was learned more efficiently.

There was a significant difference between the units and the rate of change between the units differed between the treatment and the control groups. The treatment group learned increasingly more efficiently than did the control group.

The t-tests reported in Tables 16 and 18 were used to determine the significance of changes between the units between the groups and within the groups. There was no significant difference between the treatment and control groups in Unit 1, but there were significant differences in Unit 2 and in Unit 3. In Unit 2 the treatment group learned 1.5 times as efficiently as the control group; by Unit 3 this difference had increased further.

In the control group there was no difference between Units 1 and 2, but learning efficiency declined between Units 2 and 3 and between Units 1 and 3. In the treatment group the learning efficiency increased significantly from Unit 1 to Unit 2, but fell significantly between Unit 2 and Unit 3. The difference between Unit 1 and Unit 3 was not significant.

The decline in learning efficiency between Unit 2 and Unit 3 in both groups supported the view that there was a real difference in the difficulty of the material between the Units. It can, therefore, be concluded that learning became more efficient across the units in the treatment group, but less efficient in the control group.

The difference between the units caused by the treatment was dependent on ability. In the treatment group the difference between the mean scores of the high and low ability groups became progressively less as the low ability sub-group became more like the high ability sub-group during the sequence of units.

The treatment was relatively more effective in increasing the efficiency of learning in the low ability group, although it is effective in both groups. Indeed by Unit 3 the treatment low ability sub-group was learning at least as effectively as the control high ability sub-group (actually some 18.5 per cent better).

> Proposition 14. The treatment group scores lower marks in the Unit 2 test per minute of total elapsed time spent in learning between the formative test on Unit 1 and the formative test on Unit 2, than the control group. The treatment group scores higher marks in the Unit 3 test per minute of total elapsed time spent in learning between the formative test on Unit 1 and the formative test on Unit 2, than the control group. The differences between the treatment and the control groups and the differences between the units are not affected by ability or by a combination of treatment and ability.

It was predicted that, in the treatment group, an initial decline in score per unit of total time would result from the review time required for Unit 1 and the additional time spent on the original study in Unit 2. Although the procedure was expected to produce a higher formative test score on Unit 2 it was anticipated that the initial efficiency of learning would be lower.

It was further predicted that the more efficient original learning of Unit 2 consequent on the effects of the review procedure with a reduced requirement for review for that unit combined with a more efficient original learning of Unit 3 would reverse this effect by Unit 3 and that the learning efficiency as measured in this way would increase in the treatment group.

On the other hand, it was expected that, in the control group, scores would decline from unit to unit, and that time per frame would show little or no change, so that learning efficiency would decline over the sequence of units. Table 22 shows the means of total learning efficiency in units one, two and three by groups.

The analysis of variance reported in Table 20 showed that there was a significant difference in the rate of change in the marks scored per

minute of total elapsed time from unit to unit between the treatments. Learning efficiency fell from Unit 1 to Unit 2, and then rose from Unit 2 to Unit 3 in the treatment group. It remained at the same level for Units 1 and 2, and then fell from Unit 2 to Unit 3 in the control group. Learning was some 61 per cent more efficient in the control group in Unit 2, and some 29 per cent more efficient in the treatment group in Unit 3.

The t-tests reported in Tables 21 and 22 showed that there was no significant difference between the treatment and control groups on Unit 1, and that the control group took significantly less time per percentage mark on Unit 2. In addition, the tests showed that the difference between the treatment and control groups was not statistically significant on Unit 3, although the treatment group did in fact learn more efficiently.

The treatment group scored significantly higher on the formative test on Unit 3, but this was achieved at the cost of the review time required to reach mastery level on Unit 2 and the additional time spent in the initial learning of Unit 3. Learning efficiency fell significantly from Unit 1 to Unit 2 as was expected, but rose significantly from Unit 2 to Unit 3. Further research is required to test to what extent this increase in learning efficiency would continue through a longer learning sequence. The cost in extra time of the review of the previous unit and the extra time spent in the original learning was more than offset by the higher formative test scores on Unit 3 in the case in the treatment group. The significant decline in learning efficiency between Unit 1 and Unit 3 in both the treatment and the control groups probably resulted from the more difficult material in the later Unit. The effect of the treatment was not influenced by ability; it was the same for low ability and high ability students.

> Proposition 15. The treatment group obtains on the summative test and on the retention test higher percentage scores per minute of total elapsed time spent in learning, than the control group. The differences between the treatment and control groups are not affected by ability or by a combination of treatment and ability.

If the percentage scores on the summative and retention tests are each divided by the total elapsed time spent in learning, measures of the relative efficiency of learning over the entire sequence are obtained.

It was expected that higher scores would be obtained by the treatment group on both the summative and the retention tests and that the treatment group would take longer in total learning time over the entire sequence, but

that the higher scores resulting from this time expenditure would be more than proportional to the additional time spent.

It was predicted that the learning efficiency would be greater in the treatment group than in the control group for both the summative and retention tests. The results shown in Tables 23 and 25 and the analyses of variance reported in Tables 24 and 26 showed that the mean scores on both the summative and retention tests per minute of total learning time were higher in the treatment group than in the control group. The differences, although substantial (36 per cent greater in the case of the summative test and 32 per cent in the case of the retention test) failed to reach statistical significance. The propositions were not strongly supported and it was accepted that the higher scores achieved by the treatment group were gained at the cost of proportional amounts of time and effort spent in the original learning and in remediation.

There was evidence to suggest that the effect of the treatment was greater in the high ability than in the low ability group. The treatment by ability interaction just failed to reach statistical significance on the summative test, but was significant on the retention test. The relative effect of the treatment was greater for high ability students.

The results throw some light on the comparative effectiveness overall of review procedures on students of high and low mathematical ability. The lower relative efficiency of the learning of low ability students reflects the increased reliance of such students on the remediation provided, and reflects the increased investment of time and effort that such remediation requires of these students. The high ability students scored closer to criterion levels on the formative tests, so that the remediation procedures they undertook were less costly of time and effort. Moreover the high ability students scored higher on the summative and retention tests than did the low ability students, despite the fact that all students learned the material originally to at least 85 per cent criterion level. The learning efficiencies of the low ability treatment sub-group, and the low ability control sub-group were almost identical. This again suggests that the increased score achieved by the treatment low ability sub-group was achieved at the cost of significant amounts of time and effort spent in remediation. The lack of such remediation procedures in the low ability control sub-group was reflected in proportionately lower scores. The maintenance of higher levels of learning in students of lower ability would appear to be continuously dependent on the use of remediation procedures.

The treatments in the two groups were similar in that both groups learned Unit 3 to mastery standard following the first formative test. The only real difference between the two treatments at the stage of the summative and retention tests was the lack of the diagnostic and review procedure in Unit 1 and Unit 2 in the control group. The tests included material from all three units, so that the learning to mastery of Unit 3 could have been expected to increase the control group scores significantly over what they might have been in the absence of such review.

However, the review of Unit 3 proved costly in the terms of the amount of elapsed time that it took in the control group so that learning efficiency may have been adversely affected in both measures by the review time so spent.

The results of these analyses therefore must be treated with caution. It is unfortunate that the experimenter did not have the foresight to include a separate control group which did not review at any stage in the sequence. Such a group would have provided a more satisfactory comparative group for testing the extent to which the extra time spent in study and in review had been traded for higher scores on the summative and retention tests by the treatment group.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR RESEARCH AND PRACTICE

The study examined the effects of a diagnostic review procedure , the effects of mathematical ability and the interaction of these two variables on the scores obtained in the formative test for each unit, on the time taken in the original learning and in the review learning of each unit, on the total time spent in learning each unit, on the scores per unit of time taken in learning each unit of the sequence, and the changes in the formative test scores and in time taken per unit over the sequence of the three units. The scores obtained on the summative and retention tests and the relationships between the end-of-course test scores and the total time spent in learning over the sequence of three units, together with the extent to which such changes scores and relationships were influenced by mathematical ability were also considered. In the study 59 students were provided with a hierarchical learning sequence of three units on Matrix Algebra taught by means of a programmed learning textbook. The experimental group subjects were required to reach a mastery criterion level of 85 per cent by review or relearning before proceeding to the next unit in the sequence and were given enough time to reach the mastery criterion level whereas the control group students proceeded directly to the next unit whatever their score on the unit formative tests with no opportunity or time to review and relearn.

Treatment variables

There were three differences in treatment between the experimental and the control groups. The experimental group was required to reach a mastery criterion level of 85 per cent on each unit formative test, and on subsequent review tests, before proceeding to the next unit in the sequence. In addition the experimental group was set the task of reviewing and relearning material not mastered during the initial presentations, and was provided with sufficient time and help so that each student was able to reach the mastery criterion level.

These three variables were absent from the treatment for the control group. Control group students proceeded directly to the next unit whatever their score on the first two units with no requirement, opportunity or time to review or relearn. They were, however, required to review and relearn the material of Unit 3 to mastery criterion level.

Outline of Procedures

In the study the fifty-nine students from the two forms were pooled and randomly assigned to two groups, and one of those groups was randomly assigned as the treatment group. The treatment and control subjects were placed in separate classes and were taught by different teachers.

A three part programmed textbook on Matrix Algebra was used as the teaching material. There was a 20-item formative test for each unit, and there were also two parallel review tests.

Students who were required to review or relearn material because they had not reached the mastery criterion level of 85 per cent were provided with a sheet which listed references to groups of frames which corresponded to each problem on the formative and review tests. A longer programmed textbook provided the main remedial material, although tutoring by teachers or peers was used when the remediation text proved ineffective.

A 20-item summative test was used as an immediate post-test and a parallel form of this test provided a retention test used after a delay of ten days. All students studied the materials at their own rates noting the times of starting and stopping work in each class session. Subjects in the treatment group were required to review the material of Units 1 and 2 if they failed to reach the 85 per cent criterion standard. Subjects in the control group were not given the opportunity to review in Units 1 and 2. However, both the treatment and the control groups were required to review and relearn Unit 3 to the mastery criterion standard. A summative post-test was administered to all subjects following the completion of the sequence and a retention test was given ten days later.

Both the treatment and the control groups were divided into two ability sub-groups on the basis of the Morton Mathematics Test. Those subjects who scored above the median in each group formed the two high ability sub-groups and those who scored below the median the two low ability sub-groups.

Findings

Original Achievement. The scores on the first formative tests showed no difference between the treatment and the control groups in Units 1, but there were significant differences in both Unit 2 and Unit 3. There was a difference in the rate of change across the units between the two groups. The scores of the treatment group increased over the sequence with a significant difference between Units 1 and 2 and Units 1 and 3; the scores

of the control group decreased over the sequence with a significant difference between Units 2 and 3 and between Units 1 and 3. The fact that there was no significant difference in the treatment group between Units 2 and 3 and a decline between the same units in the control group suggested that Unit 3 contained more difficult material than the other units. Such a change in difficulty across a series of units is to be expected in hierarchical material.

The scores of those students in the treatment group required to review Unit 1 were significantly higher in Unit 2, but the scores of those reviewing Unit 2 were not significantly higher in Unit 3. Just over half of the students in the treatment group were still required to review in Unit 3. The scores of these students increased significantly from Unit 1 to Unit 2 and from Unit 1 to Unit 3, but there was no significant change from Unit 2 to Unit 3. The early improvement was maintained, but not increased, perhaps because of more difficult material to be learned in the later unit.

The high ability students scored higher in both the treatment and the control groups but the difference between the units was not influenced by ability or by a combination of treatment and ability. The treatment was equally effective for both levels of ability.

There was strong support in these results for the view that the increased entry behaviour skills and knowledge brought to the study of later units in the sequence by students who had been required to review and relearn the previous unit or units to the 85 per cent criterion level was a major factor in explaining the higher scores. There was also evidence that the review procedure encouraged the more careful and complete original study of the material. This provided a further explanation for the higher formative test scores in the treatment group.

Original learning time. There was no difference in the time spent on the original learning of Unit 1 by the treatment and the control groups. The treatment group spent significantly longer on Unit 2 and on Unit 3. The treatment group spent progressively longer per unit across the sequence when the original times only were measured but when the times taken were corrected for the length of the units so that the measure became time taken per frame there was no significant difference between the groups in the rate of change between the units.

High ability students in both groups spent less time per frame on the initial studies. The low ability students in the treatment group spent

significantly longer per frame. The difference between the units was not influenced by ability or by a combination of treatment or ability.

It would seem that the review procedure was perceived negatively, and that it could be avoided by more careful and complete original study of the learning materials. The higher scores resulting from the increased investment of time and effort in the original learning of the second unit may have acted as a reinforcer for its repetition on the third unit.

Review time. Within the treatment group review time became progressively shorter across the sequence of units. There were significant differences between Units 1 and 2 and between Units 1 and 3. Less time was spent in review on the last two units. When the review times of those students who were required to review in Unit 3 were analysed separately a similar pattern emerged. The higher scores achieved on the formative tasks reduced the number of students required to review and reduced the amount of material to be studied in relearning. Just over half the students in the treatment group were still required to review in Unit 3 suggesting that there were some students for whom review learning involving the expenditure of significant amount of time was a requirement if they were to maintain mastery levels of learning.

The control group was required to review and relearn Unit 3 to mastery criterion level and took longer than the treatment group in review time on that unit. There was no significant difference between the two groups in the total review learning time over the three unit sequence. The control group took almost as long in reviewing and relearning the material of Unit 3 as the treatment group spent in reviewing material on Units 1, 2 and 3. The treatment group's higher entry level behaviours and the higher scores resulting from a more thorough original learning of the units together with a familiarity with the review requirements provided an explanation for this.

Total time. Within the treatment group the total time spent per frame declined across the sequence of units. The time measurement included original time and review time. There was a significant difference between Units 1 and 2 and Units 1 and 3. Material learned in the latter two units was mastered at a faster rate than in the first unit. There is evidence that the material of Unit 3 was more difficult, but this more difficult material was mastered at the same rate as the somewhat easier material of Unit 2. The improvement in the rate of learning of the low ability sub-group was greater than that of the high ability sub-group. This improvement

reflects the more effective original learning of subsequent units of the sequence resulting from higher entry level behaviours and more effective study patterns, which in turn led to a reduction in the review learning required. Learning effectiveness as measured by the time spent per frame increased across the learning sequence in the treatment group.

The control group was required to review and relearn Unit 3 to mastery criterion level and took longer in total time in learning that Unit than did the treatment group. The control group had come to the learning of Unit 3 with lower entry level behaviours and with less effective study patterns than the treatment group.

Learning efficiency. The original score on the first formative test of each unit was divided by the number of minutes spent per frame on original learning to give a measure of relative learning efficiency. This measure showed a difference in the rate of change between the units; the difference between the two groups became progressively greater from unit to unit. There was no difference between the groups on Unit 1, but there were significant differences between the groups on Units 2 and 3.

In the control group there was no difference between Unit 1 and 2, but learning efficiency declined between Units 2 and 3 and there was a significant decline between Units 1 and 3. In the treatment group there was an increase between Units 1 and 2, a decline between Units 2 and 3 and there was no significant difference between Units 1 and 3. It would appear that the more difficult material of Unit 3 was learned at least as efficiently as the easier material of Unit 1 in the treatment group, but not as efficiently in the control group.

The high ability groups scored significantly higher per unit of time spent on original learning, but the difference between the high ability and low ability groups became progressively less across the series of units; the low ability sub-group became more like the high ability sub-group during the sequence of units. The treatment would appear to be most effective in increasing the original learning efficiency of the low ability group. The group was apparently encouraged to spend the additional time required for better learning and the higher entry level behaviours brought to later units increased the effectiveness of subsequent original learnings.

A measure involving the original achievement score divided by the total elapsed time since the previous formative test (review time on the previous unit plus the original learning time on the present unit) was used to

compare changes in the overall learning efficiency of both groups over the sequence.

There was a significant difference in the rate of change from unit to unit between the two groups. There was no significant difference between the two groups on Unit 1, there was a difference on Unit 2 but the difference in Unit 3 was not statistically significant. Learning efficiency as measured in this way was significantly lower in the treatment group in Unit 2. The review procedure used to relearn the material of Unit 1 required the expenditure of additional time which was not compensated for by the higher scores obtained on the Unit 2 formative test. There was no statistical difference between the groups on Unit 3. The treatment group scored higher on the Unit 3 formative test, but this was achieved at the cost of the review time required on Unit 2 and the additional original learning time used on Unit 3, so that the overall learning efficiency was not statistically greater. It was in fact some 29 per cent greater. The changes between the units were influenced by ability; the low ability sub-groups taken together scored relatively higher on Unit 3 compared with Unit 1, than did the high ability groups. It was concluded that the treatment was equally effective with low ability and high ability students.

Summative and retention tests

The treatment group scored significantly higher on both the summative and retention tests. The scores on the tests were divided by the total time spent on learning through the three unit sequence to measure overall learning efficiency. The higher scores achieved by the treatment group were gained at the cost of time spent in learning and/or in remediation. Although learning efficiency was higher in the treatment group in both measures the differences failed to reach statistical significance. The relative effect of the treatment was greatest in the high ability group.

The lower relative learning efficiency of low ability students reflected the increased reliance of such students on the remediation provided, and the increased amounts of time and effort that such remediation required of these students. The increased summative and retention test scores of these students was achieved at the cost of significant amounts of time spent in remediation.

These comparisons must be treated with some caution since both groups had been required to relearn Unit 3 to the mastery criterion levels. The learning involved the control group in considerable amounts of review time

and the effect of this review time on the summative and retention scores is unclear.

Conclusion

This study has shown that the use of a diagnostic and review procedure results in progressively higher achievement scores over a series of hierarchical units. The review procedures undertaken at the end of each unit resulted in higher entry level behaviours being brought to the learning of the next unit; the later learning thus would be made more effective. The review procedure encouraged a more complete original learning of the material which took more time and this more careful learning contributed to the higher achievement scores on the later units. The review time spent on later units declined because of the higher scores obtained on the formative tests.

To measure the original learning efficiency on each unit the formative test scores were divided by the original learning time. The review group's learning measured in this way became progressively more efficient across the units compared with the control group. The scores increased more rapidly than did the original learning time but this increase was achieved at the cost of the time spent on the review learning of the previous units. When the review time spent on Unit 2 was added to the original learning time of Unit 3 the learning efficiency of the treatment group was not significantly greater than that of the control group. The higher score on Unit 3 was achieved at the cost of proportional amounts of additional time spent in review and original learning. Nevertheless, there was a significant increase in learning efficiency as measured in this way between Units 2 and 3. Examination of a longer learning sequence is recommended to test the extent to which such improvement might continue.

High ability students scored higher on the unit formative tests and on the summative and retention tests and spent less time in original learning per frame and in total learning time per frame. They scored higher per unit of time spent in original learning and per time spent in total learning on the formative tests at the end of the sequence and on the retention test.

The treatment appeared to be equally effective for both levels of ability, except that the decline in the total time spent per frame over the sequence was greater in the low ability sub-group, and that the score per unit of time spent in the original learning of each unit increased

more rapidly in the low ability sub-group. The low ability sub-group became more like the high ability sub-group. However, the relative effect of the treatment was greatest in the high ability group when the learning efficiency was measured as the score on the retention test divided by the total time spent in learning over the complete sequence of units. Low ability students were particularly reliant on the remediation procedures to maintain the high levels of learning demanded.

The diagnostic review procedure resulted in progressively higher achievement scores over a series of hierarchical units and in higher summative and retention test scores; the efficiency of learning such units in terms of the mark per unit of original learning time became greater across the sequence of units; the time spent in review declined across the units.

The increased scores and increased original learning efficiency reported were achieved at the cost of the time spent in learning and in review.

Recommendations for further research

There are four recommendations for further research arising from the findings of this study. There should be replications of the study using a learning program involving more units. The trends in original achievement, in original learning time, in review time, in original learning efficiency and in total learning efficiency established in this study could be tested more thoroughly over a longer series of units.

The nature of the relationship between scores and time taken over the whole sequence of units needs re-examination. Such a study should require a control group to proceed throughout the entire sequence to the summative and retention tests without review, enabling the end of course scores, the total times involved and the relationships between them to be directly compared.

There is a need for an examination of the changes in test scores and in review times from unit to unit when the initial presentation takes the same time for all students. Replication of the experiment using a class-teaching presentation, followed by review for those students who fail to reach the mastery criterion level, would enable such changes and relationships to be examined.

This study should be replicated using non-linear, non-hierarchical factual subject matter to investigate whether the trends exhibited in this investigation would be found using such learning materials.

Implications for Practice

The major implication for practice which stems from this study is that the provision of a diagnostic review procedure, together with the requirement for students to reach a high mastery criterion level before being permitted to proceed to later units in a hierarchical learning sequence and the allowance of sufficient time for students to undertake the relearning that is necessary, will significantly increase achievement. This will be so whether the learning is measured during the learning sequence, at the end of the learning sequence or after a time interval has elapsed following learning.

There is evidence in the study that the diagnostic review procedure encourages a more careful initial learning of later units and that this expenditure of time produces higher formative test scores thereby decreasing the time required for later review. The higher scores and the reduced need for review may act as reinforcers for the repetition of the high effort learning.

Over such a learning sequence mean achievement will progressively increase towards the mastery level. The significance of the entry level behaviours which students bring to the study of the later material is thus emphasized. As the level of prior learning increases so too does the effectiveness of later learning. The importance of teaching for mastery in the early stages of a learning sequence is thus underlined. The mean time required for remediation is progressively reduced during a sequence of units.

However, there are considerable individual differences in the amount of time and effort required for both initial learning and remediation. There is a strong implication that teaching strategies should take these differences into account. Provision should be made for those students who finish the learning before others do. Opportunity should be given for them to engage in new or extended learning. There will be a need in curriculum planning to distinguish the subject material and skills for which there will be a requirement for mastery from enrichment material and activities which will be made available to those students who have satisfactorily completed the required learning.

Although there is evidence to suggest that review time declines for many students during learning sequences there will be some students who will require the provision of significant amounts of remediation time if they are

to maintain their learning at the high mastery standard. The teaching strategy used should provide students with the time they need for learning and with incentives to use that time profitably. Time invested in the initial stages of learning increases the effectiveness of later learning because later learning becomes more efficient in terms of achievement per unit of time spent and slower learners become more like the faster learners as the learning sequence proceeds.

A further implication for practice stems from the role which remediation plays in maintaining high levels of learning. The information on the extent of learning and the identification of difficulties which diagnosis provides and the consequent review and relearning would seem to be of most value when provided early. The regular provision of such help and assistance in overcoming difficulties and misunderstandings throughout the learning program appears to be more effective than such assistance provided at the end of a sequence of units.

The use of a mastery learning procedure which provides diagnosis and review throughout the learning process has the potential to increase achievement, to improve the rate at which new material is understood and learned and thus to increase the effectiveness and efficiency of classroom and school learning.

APPENDIX

TABLES

Table 1 Means and Standard Deviations of Scores on Formative, Summative and Retention Tests and T-Tests of Differences Between the Means of the Treatment and Control Groups

Test	Treatment Group		Control Group		
	$\bar{X}$	SD	$\bar{X}$	SD	t
Formative Test, Unit 1	10.66	4.17	10.10	3.32	.539
Formative Test, Unit 2	14.70	3.65	9.90	3.52	5.143***
Formative Test, Unit 3	15.12	3.71	8.07	3.96	7.108***
Summative Test	11.40	3.35	8.97	3.07	3.171***
Retention Test	13.37	2.94	11.03	2.81	3.136***

*** significant at $p < 0.001$

Table 2 Summary of Analysis of Variance of Scores on the First Formative Tests for Units One, Two and Three

	SS	df	ms	F
Total	3592	176	-	
Between subjects	1964	58	-	
Treatment	760	1	760	68.10***
Ability	566	1	566	50.72***
Treatment x ability	24	1	24	2.15
Error	614	55	11.16	
Within groups	1628	118	-	
Units	118	2	59	5.57**
Units x treatment	327	2	163.5	15.42***
Units x ability	15	2	7.5	.71
Units x treatment x ability	2	2	1.	.09
Error	1166	110	10.60	

*** significant at $p < 0.001$
** significant at $p < 0.01$

Table 3 T-Tests of Differences Between Mean Formative Test Scores of Pairs of Units in the Treatment and Control Groups

Units	Treatment Group n	Treatment Group t	Control Group n	Control Group t
1 and 2	30	5.32***	29	.40
2 and 3	30	.79	29	3.45**
1 and 3	30	5.79***	29	2.78**

** significant at $p < 0.01$
*** significant at $p < 0.001$

Table 4 Mean Scores on the Formative Test of Treatment Group Students Required to Review

Unit	n	Reviewing Each Unit $\bar{X}$ on Unit Test	$\bar{X}$ on Subsequent Unit Test	Reviewing Unit 3 n	Reviewing Unit 3 $\bar{X}$
1	30	10.66	14.70	16	9.44
2	19	12.37	13.42	16	12.56
3	16	12.50	-	16	12.50

Table 5 T-Tests of the Differences Between Mean Scores on Unit Tests of Treatment Group Students Required to Review

Units	Reviewing Each Unit n	Reviewing Each Unit t	Reviewing Unit 3 n	Reviewing Unit 3 t
1 and 2	30	5.270**	16	2.749**
2 and 3	19	1.329	16	.077
1 and 3			16	2.698**

** significant at $p < 0.01$

Table 6 Means and Standard Deviations of Original Learning Times and T-Tests of the Differences Between the Means of the Treatment and Control Groups

Unit	Treatment Group $\bar{X}$	SD	Control Group $\bar{X}$	SD	t
1	11.97	6.34	10.14	2.25	1.486
2	19.97	12.12	15.86	4.18	1.751*
3	33.13	18.89	24.90	5.54	2.287*

* significant at $p < 0.05$

Table 7 Means and Standard Deviations of Unit Three Review and Total Times and All Unit Original, Review and Total Times and T-Tests of the Differences Between the Means of the Treatment and Control Groups

Times	Treatment Group $\bar{X}$	SD	Control Group $\bar{X}$	SD	t
Unit 3, Review	12.50	21.83	50.17	24.57	6.231***
Unit 3, Total	45.63	38.18	75.07	26.52	3.449*
All Units, Original	64.60	31.12	50.90	12.22	2.326*
All Units, Review	52.60	47.50	50.17	24.57	.248
All Units, Total	117.20	75.00	101.07	29.15	1.096

*** significant at $p < 0.001$
* significant at $p < 0.05$

Table 8 Means and Standard Deviations of Review Times in the Treatment Group

Unit	Whole Group n	$\bar{X}$	SD	Those Required to Review in Unit 3 n	$\bar{X}$	SD
1	30	29.33	23.23	16	36.13	26.42
2	30	12.43	15.44	16	17.69	14.26
3	30	12.50	21.83	16	23.44	25.45

Table 9 T-Tests of Differences Between Mean Review Times of Pairs of Units in the Treatment Group

Units	Whole Group t	Those Required to Review in Unit 3 t
1 and 2	3.66***	2.48*
2 and 3	.02	.86
1 and 3	4.42***	2.14*

*** significant at $p < 0.001$
* significant at $p < 0.05$

Table 10 Review Time as a Percentage of Total Time and of Original Learning Time in the Treatment Group

Units	Percentage of Total Time	Percentage of Original Time
1	76.9	245.0
2	38.4	62.3
3	27.4	37.7
1, 2 and 3	54.8	81.4

Table 11 Summary of Analysis of Variance of Original Learning Times

Source	SS	df	ms	F
Total	28318	176		
Between subjects	9636	58		
Treatment	987	1	987	6.50*
Error	8649	57	115.74	
Within subjects	19668	118		
Units	9754	2	4877	64.54***
Units x treatment	1299	2	649.5	8.59***
Error	8615	114	75.57	

*** significant at $p < 0.001$
* significant at $p < 0.05$

Table 12 Means of Learning Rate

Group	n	Unit 1 $\bar{X}$	Unit 2 $\bar{X}$	Unit 3 $\bar{X}$
Treatment	30	.85	.87	1.04
Control	29	.72	.69	.78
Treatment/High Ability	15	.63	.54	.79
Treatment/Low Ability	15	1.07	1.20	1.28
Control/High Ability	15	.66	.66	.81
Control/Low Ability	14	.78	.72	.74

Table 13 Summary of Analysis of Variance of Learning Rate

Source	SS	df	ms	F
Total	2885	176	-	
Between subjects	1999	58	-	
Treatment	160	1	160	7.37**
Ability	386	1	386	17.78***
Treatment x Ability	259	1	259	11.93**
Error	1194	55	21.71	
Within subjects	886	118	-	
Units	60	2	30	4.24*
Units x Treatment	13	2	6.5	.92
Units x Ability	18	2	9	1.27
Units x Treatment x Ability	16	2	8	1.13
Error	779	110	7.08	

*** significant at $p < 0.001$
** significant at $p < 0.01$
* significant at $p < 0.05$

Table 14 Mean Total Learning Time per Frame in the Treatment Group

Group	n	Unit 1 $\bar{X}$	Unit 2 $\bar{X}$	Unit 3 $\bar{X}$
Treatment	30	2.81	1.40	1.43
Treatment/High Ability	15	1.60	.75	.90
Treatment/Low Ability	15	4.01	2.05	1.95

Table 15 Summary of Analysis of Variance of Total Adjusted Learning Time in the Treatment Group

Source	SS	df	ms	F
Total	211	89	-	
Between subjects	119	29	-	
Ability	57	1	57	25.79***
Error	62	28	2.21	
Within subjects	92	60	-	
Units	39	2	19.5	23.78***
Units x Ability	7	2	3.5	4.27*
Error	46	56	.82	

*** significant at $p < 0.001$
* significant at $p < 0.05$

Table 16 Mean Original Learning Efficiency and T-Tests of Differences Between Treatment and Control Groups

Group	n	Unit 1		Unit 2		Unit 3	
		$\bar{X}$	t	$\bar{X}$	t	$\bar{X}$	t
Treatment	30	5.93		7.94		6.47	
Control	29	5.39	.60	5.24	2.64**	3.67	3.68**
Treatment/High Ability	15	8.61		11.07		7.75	
Treatment/Low Ability	15	3.25		4.81		5.18	
Control/High Ability	15	6.94		6.23		4.37	
Control/Low Ability	14	3.74		4.21		2.92	

** significant at $p < 0.01$

Table 17 Summary of Analysis of Variance of Original Learning Efficiency

Source	SS	df	ms	F
Total	2376	176	-	
Between subjects	1758	58	-	
Treatment	189	1	189	10.73**
Ability	531	1	531	30.14***
Treatment x Ability	69	1	69	3.92
Error	969	55	17.62	
Within subjects	618	118	-	
Units	70	2	35	8.86***
Units x Treatment	37	2	18.5	5.23**
Units x Ability	49	2	24.5	6.92**
Units x Treatment x Ability	28	2	14	3.54*
Error	438	110	3.95	

*** significant at $p < 0.001$
** significant at $p < 0.01$
* significant at $p < 0.05$

Table 18 T-Tests of the Differences Between Means of Original Learning Efficiency of Pairs of Units in the Treatment and Control Groups

Units	Treatment Group n	Treatment Group t	Control Group n	Control Group t
1 and 2	30	3.856***	29	.367
2 and 3	30	2.054**	29	3.805***
1 and 3	30	.776	29	4.516***

*** significant at $p < 0.001$
** significant at $p < 0.01$

Table 19 Means of Total Learning Efficiency

Group	n	Unit 1 $\bar{X}$	Unit 2 $\bar{X}$	Unit 3 $\bar{X}$
Treatment	30	5.93	3.26	4.73
Control	29	5.39	5.24	3.67
Treatment/High Ability	15	8.61	5.00	6.51
Treatment/Low Ability	15	3.21	1.53	2.95
Control/High Ability	15	6.94	6.22	4.37
Control/Low Ability	14	3.49	3.93	2.73

Table 20 Summary of Analysis of Variance of Total Learning Efficiency

Source	SS	df	ms	F
Total	1900	176	-	-
Between subjects	1369	58	-	-
Treatment	1	1	1	.06
Ability	452	1	452	28.34***
Treatment x Ability	39	1	39	2.45
Error	877	55	15.95	-
Within subjects	531	118	-	-
Units	82	2	41	13.18***
Units x Treatment	78	2	39	12.54***
Units x Ability	22	2	11	3.54*
Units x Treatment x Ability	7	2	3.5	1.13
Error	342	110	3.11	-

*** significant at $p < 0.001$
* significant at $p < 0.05$

Table 21 T-Tests of the Differences between Means of Total Learning Efficiency of the Treatment and Control Groups

Unit	t
1	.60
2	2.62*
3	1.31

* significant at $p < 0.05$

Table 22 T-Tests of the Differences between Means of Total Learning Efficiency of Pairs of Units in the Treatment and Control Groups

Units	Treatment Group		Control Group	
	n	t	n	t
1 and 2	30	6.272**	29	.367
2 and 3	30	2.857**	29	3.805**
1 and 3	30	1.921*	29	4.516**

** significant at $p < 0.01$
* significant at $p < 0.05$

Table 23 Means of Achievement Learning Efficiency by Groups

Group	n	$\bar{X}$
Treatment	30	7.50
Control	29	5.51
Treatment/High Ability	15	11.46
Treatment/Low Ability	15	3.54
Control/High Ability	15	7.43
Control/Low Ability	14	3.45

Table 24 Summary of Analysis of Variance of Achievement Learning Efficiency

Source	SS	df	ms	F
Total	1593	58	-	-
Treatment	55	1	55	3.17
Ability	517	1	517	29.8***
Treatment x Ability	68	1	68	3.92
Error	953	55	17.33	

*** significant at $p < 0.001$

Table 25 Means of Retention Learning Efficiency by Groups

Group	n	$\bar{X}$
Treatment	30	8.48
Control	29	6.44
Treatment/High Ability	15	12.70
Treatment/Low Ability	15	4.26
Control/High Ability	15	8.08
Control/Low Ability	14	4.69

Table 26 Summary of Analysis of Variance of Retention Learning Efficiency

Source	SS	df	ms	F
Total	1631	58	-	-
Treatment	62	1	62	3.58
Ability	518	1	518	29.92***
Treatment x Ability	100	1	100	5.78**
Error	951	55	17.31	

*** significant at $p < 0.001$
** significant at $p < 0.01$

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This paper reports an investigation which evaluated the effects of a diagnosis and review procedure on achievement, time taken and learning efficiency in a self-paced hierarchical programmed learning sequence. The study examined changes in the three variables over a sequence of three learning units and was also concerned with the extent to which the results were influenced by mathematical ability. It was shown that the provision of diagnosis and review, together with the requirement to reach a high mastery criterion level before being permitted to proceed to later units, increased student achievement significantly but that additional time was required. The importance of the time spent in review in maintaining the higher levels of learning was emphasized. There was evidence in favour of the view that the increased knowledge and skills brought to the study of later units was a factor in explaining the higher scores and the increasing learning efficiency of the experimental group in the later units. There were considerable differences within the experimental group in time taken and in learning efficiency.

The study suggests that the use of a teaching strategy which provides diagnosis and review throughout the learning process has the potential to increase achievement and to improve the rate at which new material is learned.

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